Orbital Syngas Commodity Augmentation Reactor (OSCAR)

Thomas McClure
Kennedy Space Center
Mechanical Engineering
Fall 2018 Session
12/14/2018

Orbital Syngas Commodity Augmentation Reactor (OSCAR)

Thomas S. McClure[1]
University of Missouri, Columbia, Missouri, 65203

The goal of the Orbital Syngas Commodity Augmentation Reactor (OSCAR) project is to study and develop Trash to Gas (TtG) technology in a microgravity environment. This could be implemented on the International Space Station (ISS) and future deep space exploration missions involving long-term human habitation. TtG technology will be used to convert trash and human waste into useful gasses such as methane, hydrogen, water, and carbon dioxide. This will both reduce the spacecraft pressurized volume dedicated for waste storage and provide gaseous commodities that have energy storage and life support applications. As a fall 2018 intern on the OSCAR team at Kennedy Space Center, I helped to prepare the experimental setup for microgravity testing in the drop tower at Glenn Research Center.

Nomenclature

OSCAR	=	Orbital Syngas Commodity Augmentation Reactor
TtG	=	Trash to Gas
ISS	=	International Space Station
GRC	=	Glenn Research Center
KSC	=	Kennedy Space Center
ConOps	=	Concept of Operations
ACL	=	Applied Chemistry Laboratory

I. Introduction

Four astronauts on the ISS can generate more than 5500 lbs of trash in a single year, which is equivalent to the weight of around 5 full-grown Floridian manatees. Waste is allowed to accumulate in a dedicated module of the station before the entire module is ejected into the Earth's atmosphere for burnup on re-entry. This trash takes up valuable pressurized storage space and can represent health and safety hazards for the crew. Conversion of waste into useful commodities not only reduces volume and is more hygienic, it also more efficiently uses mass that was launched into orbit at great expense.

Figure 1. Trash accumulated on the ISS.

On deep space missions involving human habitation, such as the Lunar Gateway and Mars exploration missions, the question of what to do with trash will be even more important. Without TtG technology, trash will either need to be stored in the spacecraft for the duration of the mission, or ejected into space as debris. Aside from alleviating the trash storage problem, the technology developed through the OSCAR project could also help to reduce the need for deep space resupply missions. Methane and hydrogen can be used as propellant, and water is a valuable life-support commodity. All three of these gases are potential products of TtG reactions.

Before implementation of TtG technology on the ISS, it must be validated in microgravity. The goal of the OSCAR project is to provide this validation using a series of microgravity tests. First, a reactor payload will be tested using the 2 second drop tower at Glenn Research Center (GRC), where it will be dropped from a height of approximately 8 stories to achieve a full 2.2 seconds of free fall. Next, it will be tested at GRC's Zero Gravity Facility, where it will be dropped inside a 432 foot tall vacuum chamber to achieve a full 5.18 seconds of free fall with no aerodynamic drag. Finally, a reactor payload will be developed for a sub-orbital flight on-board a commercial rocket, where it will experience 3 minutes of microgravity.

[1] Undergraduate Student, Department of Mechanical and Aerospace Engineering, University of Missouri - Columbia

II. Steam Enriched Gasification

The microgravity tests conducted by the OSCAR team will utilize steam enriched gasification to achieve conversion of trash to gas. Steam enriched gasification consists of combustion, Eqn. (1), and steam reformation. The steam reformation reaction consists of the three steps shown in Eqns. (2-4).

$$C_nH_{2m} + \left(n + \frac{m}{2}\right) O_2 \rightarrow nCO_2 + mH_2O, \tag{1}$$

$$C_nH_m + nH_2O \rightarrow \left(n + \frac{m}{2}\right) H_2 + nCO \tag{2}$$

$$CO + 3H_2 \rightarrow CH_4 + H_2O \tag{3}$$

$$CO + H_2O \rightarrow H_2 + CO_2 \tag{4}$$

Assuming complete reaction, no impurities, and that the fuel (trash) consists of carbon and hydrogen only, the output of the reactor is a mixture of methane, hydrogen, water, and carbon dioxide, while the input to the reactor is water, oxygen, and fuel.

Oxygen is supplied to the reactor using a pressurized cylinder and the water is injected using a syringe pump. Both the oxygen and the water lines are preheated to 150°C using electric heaters and then are mixed together and heated to 300°C. This temperature is above the auto-ignition point of the trash simulant material (cotton or plastic). After injection of trash simulant into the reactor, the TtG reaction begins spontaneously and is sustained by the even higher temperatures created by the exothermic reaction. The outlet to the reactor is connected to three collection bottles, which collect reactor output during the pre-experimental, experimental, and post-experimental phases. The composition of the gas in all three bottles is analyzed using a gas chromatograph. Footage of the reaction is captured using a GoPro Hero6 Black camera at 240 fps. A high level diagram of the experimental setup is shown in Fig. 2.

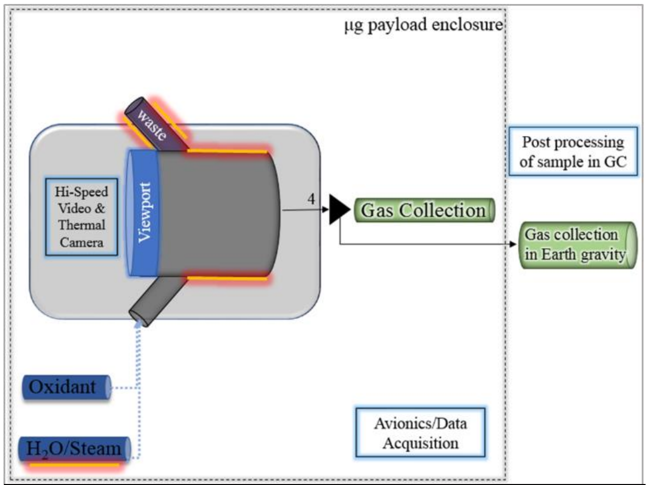

Figure 2. High-level diagram of experimental setup.

III. Shock Testing

Before sending the setup to GRC for the 2s drop tower experiments, it was subjected to a 35g shock in the vibration lab at KSC. This test was conducted to verify that no failures would occur on landing at the 2s drop tower, which is 8 stories tall. The fall is cushioned using an inflatable air bag, which quickly deflates on impact to slow the rate of deceleration. Even with the air bag cushioning, it was recommended that the experimental setup should be able to sustain acceleration loading of 35g. The shock test was recorded using high framerate cameras and the footage was viewed in slow motion in order to determine the locations of greatest flexing. Although the shock test was successful and there were no critical failures, it was determined that further support should be added in two locations. A piece of angle material was bolted to the bottom of the stainless steel shelf on which the reactor was placed, and an additional support was added to the bottom of the trash injection tube, to add stiffness and reduce flexing.

IV. Contributions

During the first half of this internship, I helped construct the experimental setup which will be used for the drop tower tests at GRC and conduct lab testing to generate baseline control data. My contributions during this phase consisted of mechanical design, electrical wiring, and testing support. After the setup is sent to GRC on November 6^{th}, I will contribute to the design of the new experimental setup that will be used for the sub-orbital flight.

A. Mechanical Design

Drop testing exposes the experimental setup to peak accelerations of 35g (for the 2s test) and 65g (for the 5s test). This high loading necessitates very secure mounting of all reactor components, including sensors, bottled gasses, tubing, and valves. One of my responsibilities was to ensure that all components on the rig were mounted appropriately to handle high gravitational loading, particularly in the downward direction. To accomplish this, I 3D printed brackets for many components and sections of tubing.

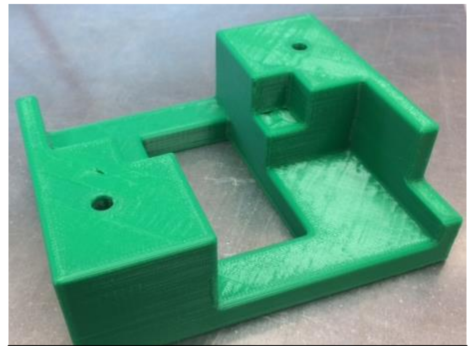

Figure 3. 3D printed camera mount.

The experiments are monitored with five GoPro Hero6 Black cameras. Three cameras are positioned around the experimental setup to provide a view of all components, particularly the oxygen bottle, to clearly record exactly what happens in the case of a failure. Two cameras are positioned above the reactor viewport, one of which records the reaction at a high framerate, and the other records at a lower framerate. The lower framerate camera is necessary because high framerates make it impossible to live stream the recording from a mobile device. The lower framerate recording of the second camera will allow real-time monitoring of the reactor, which is critical for drop timing. Since the trash simulant doesn't combust immediately upon loading into the pre-heated reactor and it is difficult to reliably predict the precise moment of the reaction, the reactor needs to be monitored closely so that the drop can be initiated as soon as combustion begins. I mounted all 5 cameras onto the setup, and designed a custom 3D printed part for the two viewport cameras.

B. Electrical Wiring

The experimental setup for drop testing makes extensive use of electrical components and sensors, particularly pressure transducers and thermocouples. During the assembly phase prior to testing, one of my responsibilities was to support the electrical team in wiring the setup. I wired many of the thermocouples and pressure transducers, as well as several other components, according to the electrical schematic of the system.

Figure 4. Wiring some thermocouples in the ACL.

C. Testing

Before being sent to Glenn Research Center for drop tower experiments, the setup was tested several times to establish baseline control data as well as to ensure that the drop tower experiments went smoothly. Preparation of the reactor for testing involves many steps which must be done in the correct order, and all testing operations during the drop experiments needed to be automated, so this phase was critical. A Concept of Operations (ConOps) procedure was developed prior to testing and refined throughout testing to ensure that all steps were clearly articulated and listed in the correct order.

I acted as the mechanical technician for some tests, which involved following the mechanical steps of the ConOps procedure as read by the test conductor and responding to the test conductor to confirm that each step had been completed. I also helped to refine the ConOps procedure during this phase. The testing procedure included many peripheral tasks including cleaning and emptying of gas canisters into collection bags. The collected gas from the reaction is fed from the collection bag into a gas chromatograph for analysis.

V. Conclusion

The main objective of this internship was to support the OSCAR team in preparation for drop testing and sub-orbital flight experiments. Contributions to the project included mechanical design, electrical wiring, and testing activities. The experimental setup was sent to GRC on November 6^{th} and two second drop testing will be conducted until November 16^{th}. After the setup is sent to GRC, efforts will be focused on design of the new experimental setup for sub-orbital flight testing.

Acknowledgments

I would like to acknowledge my mentor, Evan Bell, and OSCAR's principal investigator, Annie Meier, for their invaluable support throughout this internship.